# THE PERIODS OF CATACLYSMIC VARIABLES

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## ABSTRACT

The present status of the period studies of cataclysmic variables is briefly reviewed, mainly from the observational point of view. A few comments on individual objects include EM Cyg, Z Cha, WZ Sge and AM CVn.

## 1. Introduction

A recent review of the periods of cataclysmic variable (CV) stars gives this assessment of the importance of these studies: the orbital period is the only one physical property known accurately for a large number of systems. Perhaps the ensuing question is justifiable: how accurately are the CV periods known? Are the available data accurate enough to furnish direct information about their evolution or the time scale of this evolution? CV periods are certainly a topic a great deal more difficult, observationally as well as theoretically, than the study of the periods of other binaries, full of unexpected difficulties and special circumstances; it also requires a more sophisticated technique of observations. Characteristically, while some of the most accurately known binary periods belong to CVs, a large number of these objects yields periods only accurate to about the next minute or so, and for perhaps a fourth of the list no period is known yet.

The review of Edward Robinson (1983) mentioned at the outset has its main emphasis on the distribution of the periods, including the elimination of the selection effects. Limited time and space suggest that in this survey we consider, however briefly, the present status of observed period variations and select but a few important objects for illustrating the opinions and suggestions. A more appropriate title of this short review could have been: Comments on the period changes of some cataclysmic binaries.

The distribution of the periods has three generally recognized basic features: a minimum orbital period at 70-80 minutes, a maximum orbital period, less sharply defined, around 16 hours

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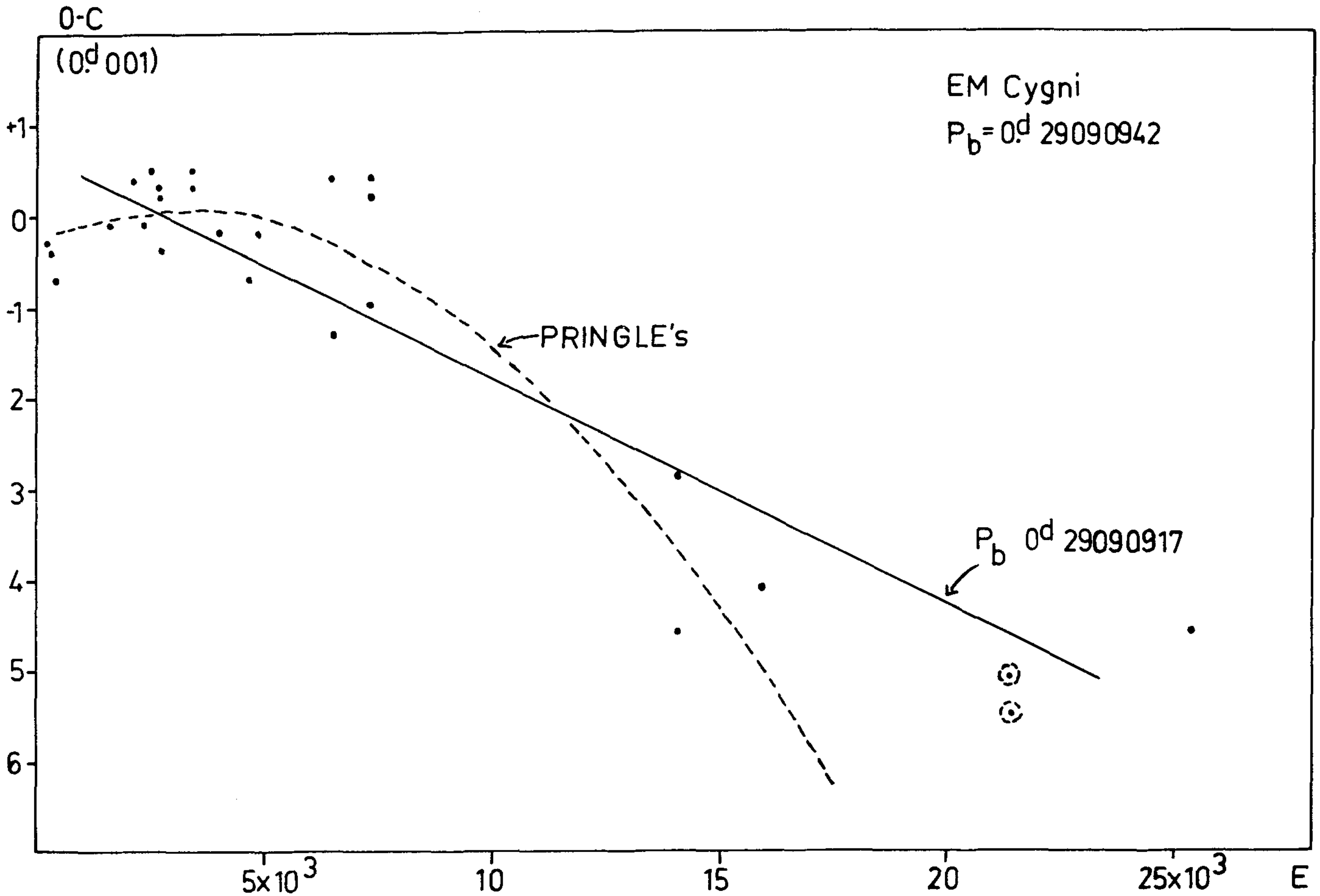


Fig. 1. Residuals (O-C) against epoch number for EM Cyg. Symbols near E = 21000 refer to O-C values determined from a small scale figure, representing the observed light curve. Minima discarded by Mumford and Krzeminski are also omitted here.

and the conspicuous gap between 2 and 3 hours. Systems believed to represent "pre-cataclysmic binaries" settle near periods of 0.5 - 1 day. The low-mass X-ray binaries, obviously a related class, count only a dozen known objects, but the distribution of the periods - as far as it can be judged from this small sample - is somewhat similar to that of the CVs. Although actual period variations can go both ways, depending on the mass flow and the balance of momentum in the system, the observed distribution of the periods suggests a prevailing direction of secularly decreasing periods, more distinguished so for shorter values. In particular, all theories of the period gap imply that the systems cross it moving from the longer to the shorter values, and finally the gravitational radiation will "inexorably" drive the components closer and closer, perhaps even to merging together.

Direct observation of the periods and period changes contribute little to this picture. In fact, there is a number of well-studied CVs where even finding the orbital period can be unusually, even embarrassingly difficult, as illustrated by the spectroscopic history of GK Per or SS Cyg. In quite a few cases, when the spectroscopic period usually was established, no photometric period was attainable; it is instructive to read the case history of V603 Aql or HR Del in a recent review by Warner (1985). For a surprising number of systems, multiple periods have been definitively established; one recent case, that of TT Ari (Thorstensen et al., 1985) should be referred to, as one particularly interesting example.

Spectroscopic periods as well as "superhump periods" (identified with the orbital period) are seldom better defined as to the next minute or perhaps 10 seconds. This accuracy is certainly insufficient for a study of <u>period variations</u>. The best periods can only be established if the CV exhibits distinct and permanent phase indicators, in most cases eclipses of the accretion disk, the hot spot or the white dwarf. In such cases - there are perhaps 20 well observed ones - the study of secular or periodic changes of the period becomes meaningful.

## 2. Secular Variations

About CVs that show these features, such as an eclipse, repetitive dip or hump, a large body of photometric observations (also by high speed photometry) has been collected and analysed for period variations, using mostly the well known procedure of the O-C diagrams. Pringle (1975) as well as Beuermann and Pakull (1984) reviewed the periods of several systems, altogether about a dozen cases. All types of CVs are represented here in a mixed collection, features of the light curves were the crucial point in selecting the objects for observation. If we ask for secular variations of the periods, the answer is somewhat disappointing. Owing to irregular distortions of the light curves, the accuracy of epoch determination is seldom higher than ±30 or ±50 seconds. Pringle's conclusion was that among 9 systems he considered, only T Aur and EM Cyg show "reasonable evidence" for a change of period. Beuermann and Pakull do question even these cases and give only upper limits of the period variations and mass exchange rates.

a) There is one system, Z Cha, where this situation improved considerably since 1975; we return to the results shortly. In most other cases we are, regrettably, unable to obtain a reliable estimate of the mass flow from timings of the minima alone. As an illustration we briefly discuss the period of the dwarf nova EM Cyg, a relatively simple and straightforward case. Pringle suggested a decrease of the period, see Fig. 1. Although a linear representation of the residuals also appeared possible, the quadratic fit was closer and for the best-fitting parabola a significance at the 99.85 percent level was quoted. Most of the earlier observations, including the apparently decisive ones near E = 14000, are from Mumford; recent observations are few and far between (Mumford, 1975,; Jameson et al., 1981; Beuermann and Pakull, 1984), yet they unmistakably favor the linear representation, that is, a constant period.

The period derived from all the "more reliable" residuals is virtually the same as Pringle's earlier best constant period, the difference being $2 \times 10^{-8}$ days, about the error of the period. The corresponding standard deviation of the timings is, on the other hand, with 0.00082 days relatively large. The parabolic fit reduces the standard deviation to 0.00056 days, still much higher than merely observational errors would correspond to. This improvement may underlie the quoted high confidence level. The latest observation yields, nevertheless, an inacceptable O-C = +0.0106 days. Thus we cannot verify the concept of a decreasing period, and one is tempted to repeat Pringle's own remark: "The reader may judge the credibility of a 99.8 percent result".

b) The most convincing case of a well documented period change, an apparently linear increase of the period of a CV, is that of Z Cha (Cook, 1985; Wood et al., 1986 and further references therein). The latest work is based on extensive high-speed photometry made at CTIO and the South African AO. The timing accuracy of the 29 minima (showing the characteristic "stepped" light curve due to the white dwarf and hot spot eclipses) is truly remarkable. Janet Wood and her colleagues derive a quadratic ephemeris which corresponds to $\dot{P} = 1.234 \times 10^{-12}$ days/period or $1.656 \times 10^{-11}$ seconds/second. The present rate of the period variation would lead to a characteristic time $P/\dot{P} = 1.23 \times 10^{7}$ years. The required rate of conservative mass transfer is, however, orders of magnitude higher than the observed value, and the authors express their doubt that conservative mass transfer alone could account for the period change. There may be a further problem with the proposed interpretation of the period changes. Consulting Fig. 4 of the paper cited, it becomes obvious that the period has increased since 1973 (the earliest observations), but it also appears that timings between 1980 and 1983 show systematically positive residuals, hardly explicable by observational errors. It should be mentioned that epochs since 1980 allow a very good fit by a constant period, $3.7 \times 10^{8}$seconds longer than the one used in calculating the linear ephemeris. An abrupt change of the period is not entirely out of question - although not a very sympathetic hypothesis due to the arbitrariness involved and the fact that no such variations were observed for any other CV. One new set of high quality observations could possibly decide this question.

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c) A secular variation of particular nature plays an important role in the evolution of close binary systems, specifically at short periods: the degradation of the orbit due to emitting gravitational waves. We may ask, what is our chance to demonstrate it directly, from the variation (linear decrease) of the period, as it has been demonstrated in the case of the binary pulsar PSR 1913+16 (Taylor and Weisberg, 1982).

We may consider WZ Sge, with P = 82 minutes period, and compare it to the binary pulsar. The simplest way is to use the formula for -dE/dt, the loss of orbital energy verified by the pulsar experiment. The power of outgoing gravitational radiation is in the case of PSR 1913+16 (taking $M_1 = M_2 = 1.4\ M_\odot$) about $4 \times 10^{23}$ W; using the catalogue values for orbit and masses of the WZ Sge system, we derive an order of magnitude less radiative power, about $3.5 \times 10^{22}$ W. This latter value has an additional uncertainty, since the reduced mass appears on the second power in the formula. Thus the calculated value depends strongly on the mass ratio of the components we use. Having translated these values to $\dot{P}$ and integrated over a few years, we obtain the phase shifts, that is, the O-C values we may expect. A phase shift of - 1 second would be reached in less than 4 years in the case of the pulsar, in about 30 years in the case of WZ Sge. The accuracy of pulsar timing allowed the radio astronomers to arrive at a parabolic fit of high degree of significance only after 7 years. Considering the residuals of the WZ Sge timings, (normal points may have an estimated error of ±6 to ±8 seconds), we can hardly hope that even a one-second shift could be established after 30 years; the reader is urged to consult the O-C diagram on p. 172 in Robinson et al., 1978. An additional problem is that - unlike the binary pulsar - the WZ Sge system is not "clean" and the effect of gravitational radiation has to be laboriously separated from effects of interaction between the components.

We may wind up these estimates with the pessimistic view that a direct, observational determination of the period decrease resulting from gravitational radiation is at present, and during the coming years, virtually impossible.

## 3. Periodic Changes

For close binary systems, the usual interpretation of apparently periodic changes of the period refers to apsidal motion or three-body orbit (light time effect). The complicated structure of CVs manifests itself in several additional phenomena to be considered in case of a secondary period:

- "spasmodic" variations of the mass flow;
- swelling or shrinking of the disk, introducing variable momentum storage;
- relative motion of the hot spot within the system.

In most systems there is no generally accepted explanation for a suspected or demonstrated secondary period. In fact, such a behavior is seldom definitely established, the strongest candidates being RW Tri and UX UMa, systems with relatively sharp, well defined eclipses. Even in the case of UX UMa, some doubt about

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the regularity of the period variations arose as Quigly and Africano (1978) found a significant departure from Mandel's earlier prediction (1965); it occurred in 1977 and almost reached the amplitude of the cycle. Two further cases repeatedly mentioned in this connection are U Gem and DQ Her. For both systems, barely one "secondary period" has been observed and the scatter in the O-C diagram is very large, approaching the proposed effect.

Apsidal motion can furnish most valuably information about the structure of the components, much needed for theories of CV evolution. It suggests itself that the "classical" treatment should be adapted to the Roche configuration of CV pairs; this has been discussed by Warner (1978) who considered UX UMa and RW Tri in particular. The P/U ratios (using the usual notation) show "normal" values, but the apsidal motion coefficients for the secondaries turn out 10 to 100 times smaller than the values expected for late main-sequence stars. They appear to be much more condensed objects than G-M dwarfs are, dwarfs imitating the structure of a giant.

In view of such interesting conclusions the question becomes crucial: how rigorously can the apsidal motion be demonstrated, the usual methods of investigation being hardly applicable? The eccentricities required for these apsidal motions are 0.03 resp. 0.02, difficult to prove even in the cases of undisturbed spectra of detached pairs. Warner refers to EA Aqr, a possibly related system somewhat "à part", and quotes the small eccentricity found by Walker and Chincarini ($0.020 \pm 0.005$). The evidence is not quite unequivocal insofar that Payne-Gaposchkin's earlier orbit (1969) was well compatible with $e = 0$. Thus the apsidal motion hinges to some extent on this orbit, and it seems very desirable, as repeatedly pointed out by Warner, to devote more attention to the eccentricities of the CV orbits.

It has been repeatedly pointed out that the peculiar, strongly interacting nature of cataclysmic binaries may offer an additional approach to the problem of apsidal motion. If the periastron passages are giving rise to observable effects such as humps or outbursts, an independent determination of the sidereal binary period (which may not be an easy task) could also reveal the apsidal motion.

Without in any way advocating the alternative hypothesis of a light time orbit, we apply here also the well-known criterion, necessary but not sufficient, supplied by the estimated mass of the third body. We may disregard DQ Her from this point of view: even if the periodic nature of the O-C diagram could be established beyond doubt, the lack of phase shifts in connection with the 71-second oscillation argues against an orbital motion of the CV system (Patterson et al., 1978). For the other systems the estimated mass and linear separation of a hypothetical third body is given in the short table below, considering a wide range of inclination values, $i = 90^{\circ}$ to $i = 30^{\circ}$. (In the case of U Gem, the amplitude of the effect has been taken from Fig. 1a in Beuermann and Pakull, 1984.)

| | | | |
|---|---|---|---|
| RW Tri: | $f(M) = 3.77 \times 10^{-4}\ M_{\odot}$ | $M_3 \approx 0.07$ to $0.15\ M_{\odot}$ | $a \approx 3$ AU |
| UX UMa: | $3.31 \times 10^{-5}\ M_{\odot}$ | $0.03$ to $0.06\ M_{\odot}$ | 9 AU |
| U Gem : | $1.87 \times 10^{-3}\ M_{\odot}$ | $0.15$ to $0.30\ M_{\odot}$ | 8 AU |

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Masses indicated for a third companion of UX UMa are too low, below the values corresponding to main-sequence stars, those for RW Tri are marginally acceptable, at best. For U Gem, the evidence is compatible with an M-type dwarf, even a low mass white dwarf as third body in the system. The hypothetical companion could be an 18th or 19th magnitude star at an angular separation of $0\overset{''}{.}03$ - $0\overset{''}{.}04$ from the CV. It may not be a hopeful candidate for visual or interferometric detection.

Existence of some CVs in triple systems would not be unexpected. Based on the (still rather uncertain) statistics of binary and multiple stars, as discussed for instance in Batten's monographe (1968), 3 or 4 systems among the known CVs might show observable light time effect.

Should the CVs be descendants of substantially wider and more massive systems, these third components may have an added significance.

## 4. A Note on AM CVn

This system (earlier designation HZ 29) of two white dwarfs forming a semi-detached configuration and with the shortest known period, 1051 seconds = 17.5 minutes, is perhaps not a CV itself, but certainly a related object, possibly descending from the CV state. We briefly mention it here because the "story" of the period and its variations is truly fascinating and probably still unfinished.

For some years various period determinations were in disagreement by several 0.1 seconds; there was also a report of a rapidly increasing period, a conclusion which proved premature. In a recent thorough study, reviewing also all previous attempts, Solheim et al. (1984) apparently succeeded in clearing up the confusing situation. They found a slowly decreasing period with the present value of 1051.0415 seconds. As the authors demonstrate, the Roche configuration of the white dwarf precludes a decrease of the orbital period, and they reinterpret the 1051 second period as corresponding to the rotation of the accreting component.

Power spectrum analysis of the light curve resulted, however, in a surprising frequency diagram: only two periods and their aliases are obvious, at 525.5 = (1051/2) seconds and at 1011.4 seconds, a hitherto unsuspected value. The 1051 second period is absent (hidden perhaps by a side lobe of the 1011 second peak?). No interpretation has been put forward for the new frequency in the power spectrum. The intriguing possibility has also been mentioned that all minima are equivalent (with no distinction between primary and secondary minimum), and the light curve is a single-humped curve with the period of 525.5 seconds.

Could we go one step further and identify this period with the orbital period? The authors do not come to this conclusion - indeed, the whole model of the system would then undergo a radical change, including a reinterpretation of the period variations.

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